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Paper No. 05-074

Comparison of GHG emissions from a compost pile and manure stockpile

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**Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 - 29, 2005**

Abstract

The objective of this study was to compare the total greenhouse gas (GHG) emissions (biogenic and non-biogenic) from a compost pile and a manure stockpile. On July 14, 2004, two piles were established using the same feedlot manure and approximately the same amount of manure in each pile. Biogenic GHG samples were collected from the surfaces of the piles using a static chamber during the active decomposition phase. Non-biogenic GHG emissions were estimated by multiplying the amount of fuel consumed by machinery operations (pile formation, turning and spreading end product) with standard fuel emissions factors. The results of the study showed that both piles emitted carbon dioxide (CO₂) throughout the trial. There was no significant ($P \geq 0.05$) difference in the CO₂ emissions from the compost pile and the manure stockpile. Methane (CH₄) emissions from the manure stockpile were significantly ($P < 0.05$) higher than from the compost pile, possibly due to anaerobic conditions inside the manure pile. Compared with CO₂ and CH₄ emissions, nitrous oxide emissions were relatively low from both piles. No significant ($P \geq 0.05$) differences were found in N₂O emissions. Non-biogenic GHG emissions from the compost pile and the manure stockpile were very small (2.5 and 11.8 kg-CO₂ equivalent per Mg initial dry mass, respectively) as compared to biogenic GHG emissions (215 and 419 kg-CO₂ equivalent per Mg initial dry mass).

Keywords: Greenhouse gas emissions, manure, compost, carbon dioxide, methane, nitrous oxide, feedlot

INTRODUCTION AND BACKGROUND

Atmospheric concentrations of greenhouse gases (GHGs) have increased dramatically since the industrial era started in 1750. For instance, carbon dioxide (CO₂) concentration has risen by 30%, methane (CH₄) concentration has doubled, and nitrous oxide (N₂O) concentration has increased by about 15 % (IPCC 1995). Greenhouse gases act to trap long-wave radiation emitted from the Earth's surface. The ability of each GHG to trap radiation depends on the particular gas's capacity to absorb radiation and is termed global warming potential (GWP). The GWPs of CO₂, CH₄, and N₂O are 1, 23 and 296 respectively (IPCC 2001). These GHGs are believed to accelerate the warming of the atmosphere and influence climate change, which is a significant international concern and is a subject of much research and debate. Today, society faces important decisions regarding climate change mitigation and concerns are being expressed about the potential implication of the build up in atmospheric concentrations of GHGs.

Canada, along with 174 nations, has ratified the Kyoto Protocol, which commits the nations to reduce their GHG emissions to 5.2% below 1990 levels. Canada has agreed to lower emissions 6% below 1990 levels over a span of five years from 2008 to 2012 (Desjardins *et al.* 2001). It is noteworthy that although Canada contributes only 2% of the total global GHG emissions, its GHG emissions are among the highest per capita. In order to achieve the reduction target set out in the Kyoto Protocol, all provincial governments in Canada are asked to explore key greenhouse-gas emitting sectors and, subsequently, to work towards the implementation of the protocol.

Apart from the key GHG-emitting areas, such as the industry and transportation sectors, the agriculture and waste management sectors have also been identified as major contributors of GHGs, accounting for 11.2% of total GHG emissions in Canada (Environment Canada 2003). According to Janzen *et al.* (1998), animal manure management is estimated to be responsible for 1.25% of GHG emissions in Canada. Manure storage releases CO₂, CH₄, and N₂O gases due to anaerobic decomposition. In 2002, manure management practices in Canada released 270 and 15 kt of CH₄ and N₂O, respectively (Environment Canada 2003).

The ratification of the Kyoto Protocol by the Canadian government has raised interest in the development of improved waste management practices that would reduce GHG emissions. Composting of organic waste is one of several potentially valuable options available to manage animal manure. Composting is gaining acceptance as an alternative to conventional methods of manure management due to associated benefits, such as easy handling and reduction in volume of organic waste (Hao *et al.* 2001). It is generally believed that aerobic composting of organic waste will also reduce the GHG emissions compared to conventional systems in which manure is simply stored before being spread on the land.

Previous research on composting has mainly focused on “composting as an effective tool for waste management” (Zeman *et al.* 2002). Very little data are currently available which quantify the total GHG emissions from composting processes. There are still large uncertainty and variability in the quantification of GHG emissions from composting (He *et al.* 2000). Although it is sometimes assumed that only CO₂ is produced during composting, this is only applicable when aerobic conditions are strictly maintained throughout the entire composting process. Several previous studies have reported, however, that CH₄ and N₂O are also produced along with CO₂ during the composting of livestock waste (Hao *et al.* 2001 and He *et al.* 2000).

A study was conducted by Hao *et al.* (2001) to analyze GHG emissions from beef feedlot manure composting using two different aeration methods: passive and active aeration. In passive aeration, the compost pile was never turned and air was supplied using open-ended perforated steel pipes (100 mm diameter) placed under the compost. In active aeration, the compost pile was turned six times during the composting process. The researchers found lower GHG emissions from passively-aerated compost due to the incomplete decomposition and a lower gas diffusion rate. The lack of turning was found to be a main factor for limiting the decomposition process. In the active aeration treatment, regular turning introduced fresh air into the windrow, and was promoted CO₂ production throughout the composting period. Their study found no significant difference in CH₄ emissions between active and passive composting although CH₄ emissions from active composting were slightly higher than from passive composting. Nitrous oxide emissions were very low compared to CO₂ and CH₄.

OBJECTIVES

Greenhouse gas emissions from composting (turned or aerated) and manure (static) stockpile can be categorized into biogenic (non-anthropogenic) and non-biogenic (anthropogenic) emissions. Biogenic emissions arise from natural decomposition of the organic matter present in the pile. Non-biogenic emissions result from the burning of fossil fuel used in the machinery required to perform different operations, from the formation of the piles to the spreading of the end-product. Most previous studies have only looked at biogenic emissions from compost, but it is important to account also for non-biogenic emissions from manure management systems.

The main objective of this research was to quantify and compare the GHG emissions from two manure management processes: composting and manure stockpiling prior to field spreading of the end product. In this project, an integrated assessment of GHG emissions from both biogenic and non-biogenic sources was attempted. Figure 1 illustrates the system boundaries for this study.

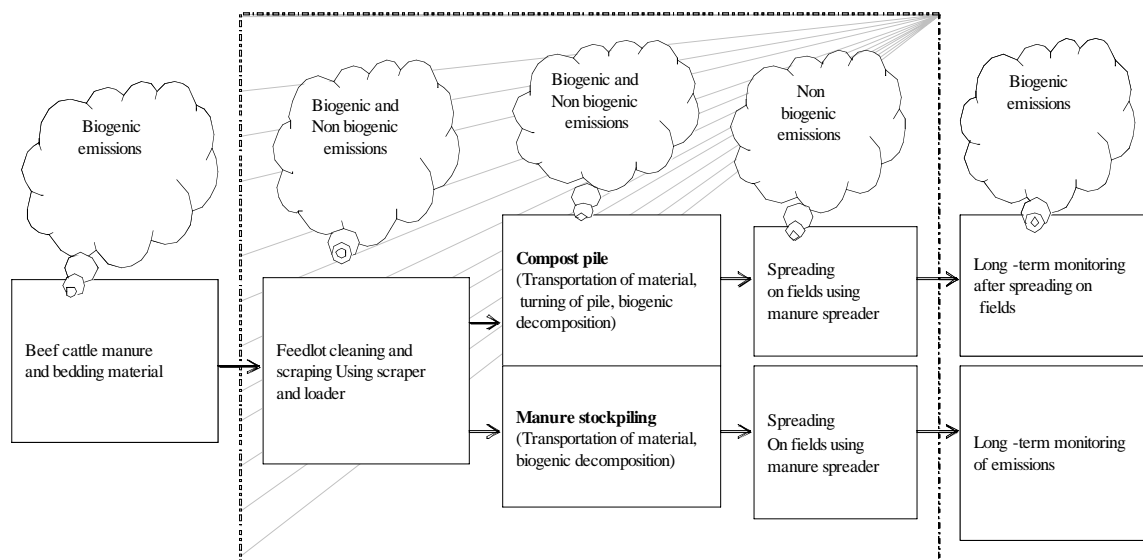


Figure 1. Material flow in manure management practices (dotted lines represent boundary)

The following specific objectives were identified in this study:

- Measurement of biogenic GHG emissions from active decomposition of beef cattle manure in composting and manure stockpiling process.
- Estimation of non-biogenic GHG emissions produced from various machinery operations in composting and manure stockpiling.
- Comparison of total GHG emissions from composting and manure stockpiling.

MATERIAL AND METHODS

Site description of beef feedlot and facility operations

The field study was conducted at the Agriculture and Agri-Food Canada Research Centre at Lethbridge, Alberta (AAFC Lethbridge) in collaboration with Alberta Agriculture, Food, and Rural Development (AAFRD). The project started on July 14, 2004 and finished on October 28, 2004. On July 14, a beef cattle feedlot at AAFC Lethbridge was cleaned out using a front-end loader. The manure pack contained cattle manure and wheat straw as bedding material which had been spread on the feedlot before the arrival of the animals and added as required during the animal occupancy. The ratio of manure to bedding material was about 4:1 on a mass basis.

The material was transported using a dump truck of 5000 kg carrying capacity (S1700, International Truck and Engine Corp., Warnerville, IL) to the selected storage site 200 m distance from the feedlot. Two different piles were constructed from the same feedlot manure parallel to each other in an east-west orientation. The initial mass of manure for the establishment of the compost windrow and the manure stockpile was determined by weighing each truckload using an electronic scale (Model-8142, Mettler Toledo, Mississauga, ON) with a maximum capacity of 60,000 kg. The initial mass in each pile was recorded and approximately the same mass of material was included in each. The compost windrow (44 x 2.5 x 1.1 m) and the manure stockpile (20 x 3.6 x 1.52 m) were formed with approximately parabolic cross-sections using a skid-steer loader (135-S, Thomas Equipment Ltd., Mississauga, ON).

The moisture content of the compost pile on day 36 was 36%, which is less than the recommended M.C. range (40%-65%) (Rynk 1992). Therefore, in order to increase the moisture content (M.C.), an additional 6000 L of water was sprayed onto the compost pile. Furthermore, in order to retain M.C, the compost pile was reshaped on Day 36. The length of compost windrow was reduced whereas the width and height were increased.

Physical and chemical properties of the material

The initial and final properties of the compost and manure (mass, bulk density, moisture content, temperature, C:N ratio) were measured at the start of the project and during the last week of the trial. Table 1 shows the initial and final properties of manure.

Table 1 Physical and chemical properties

	Mass (kg)		Bulk density (kg m ⁻³)		Moisture content (%)		Temperature (°C)		C:N ratio	
	Compost	Manure	Compost	Manure	Compost	Manure	Compost	Manure	Compost	Manure
Start	52,600	50,910	525	531	64	63	66	59	15.2:1	13.7:1
Finish	27,021	36,976	540	480	48	54	26	24	10.7:1	10:01

Biogenic GHG collection methodology

Biogenic GHG were collected from the surface of the compost windrow and manure stockpile using a static chamber technique (Figure 2). The static chamber technique has been used in several similar studies (Hao *et al.* 2001; Czepiel *et al.* 1996; Hellmann 1997; and Teshima 2003). The metal, cylindrical chamber had an open base and a volume of 3.33 L, a height of 180 mm, and a base area of 0.0184 m². It was placed on the surface of the pile for 30 minutes. Off-gas samples were collected from the top of the chamber through an opening fitted with a butyl septum. Gas samples were drawn through the butyl septum with a 30 mL gas syringe equipped with a 20-gauge needle having outer and inner diameters 0.904 and 0.584 mm, respectively.

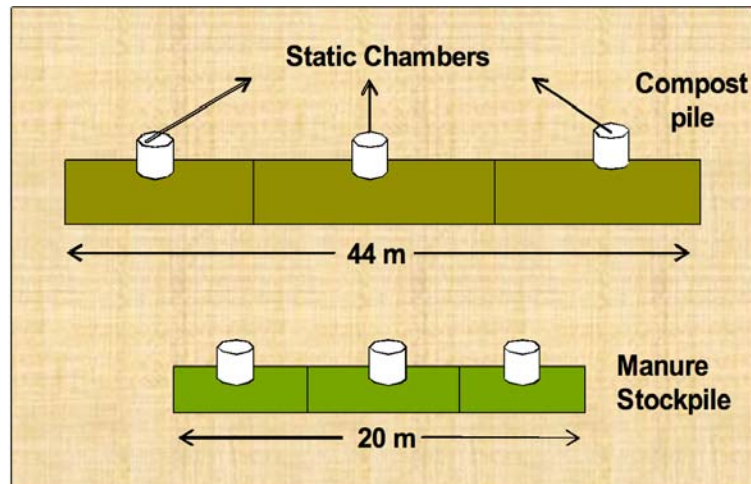


Figure 2. Experimental design for biogenic GHG sampling

Each pile was divided into three zones by dividing the length of pile into three equal sections (Figure 2). A static chamber was placed in each zone. Ten gas samples were collected from each zone on every sampling day so that a total of 30 gas samples were collected from each pile. A total of 600 biogenic GHG samples were collected on Days 1, 2, 8, 15, 22, 29, 36, 43, 57 and 79 from the compost and manure stockpile. Gas samples were collected at 0, 5, 10, 20, and 30 min with two samples taken at each time interval. The average concentration of the two gas samples were used in the analysis of the results. The gas samples were transferred into 10 mL evacuated vials (Exetainer™, Labco Limited, Buckinghamshire, UK). The vials were pre-evacuated to 90 kPa using a vacuum pump (SpeediVac, Sussex, UK) attached to a manifold of four hypodermic needles. After Day 15, the static chambers were covered with plastic containers while sampling to shield them from sun and wind. The sample vials were stored in a cooler at 4°C until analysis.

Biogenic GHG analysis using gas chromatography

For analysis of GHGs, the sample vials were transported in an ice-packed cooler to a laboratory in the Department of Agricultural, Food and Nutritional Science, University of Alberta (Edmonton, AB). Greenhouse gas concentration was analyzed using gas chromatography (GC). Carbon dioxide and methane gas concentrations were analyzed using a Hewlett Packard 5890 Series II GC (Agilent Tech. Co., Mississauga, ON) equipped with a thermal conductivity detector (TCD). The gases were separated on a HP-Plot Q capillary column (30 m x 0.053 mm ID) (Agilent Tech. Co.). The injector and column temperatures were maintained at 50°C and the

detector temperature was maintained at 80°C. The column head pressure was kept at 27.5 kPa and the injector was set for 20:1 split injection. Data integration was performed using Shimadzu Class VP Software (Chromatograph Laboratory Automated Software System Version 4.2, Shimadzu Scientific Instrument Inc., Columbia, MD).

Nitrous oxide gas concentrations were analyzed using a Varian Start 3400 Series GC (Analytical Instrument Inc., Golden, CO) equipped with an electron capture detector (ECD). N₂O gas was separated on a Poropak-Q S 80/100 1525 x 3.2 mm stainless steel column (Varian Start GC manual). The injector and column temperatures were maintained at 60°C and the detector temperature was maintained at 300°C. Gas samples were injected automatically using a multi-port injector system. The column head pressure was kept at 206.85 kPa and the carrier flow rate was maintained at 30 mL min⁻¹. Varian G Star Chromatography Workstation Version-5 software (Analytical Instrument Inc.) was used to analyze the data.

Greenhouse gas concentrations were recorded in μL L⁻¹. Concentrations were plotted against the time at which the gas samples were collected (0, 5, 10, 20, 30 min) and linear regression was used to estimate the best-fit curve. The GHG emission rates were estimated by assuming a linear increase of GHG concentration over time and calculating the slope of the best fit line (μL L⁻¹ s⁻¹). An example of a GHG accumulation curve is shown in Figure 3.

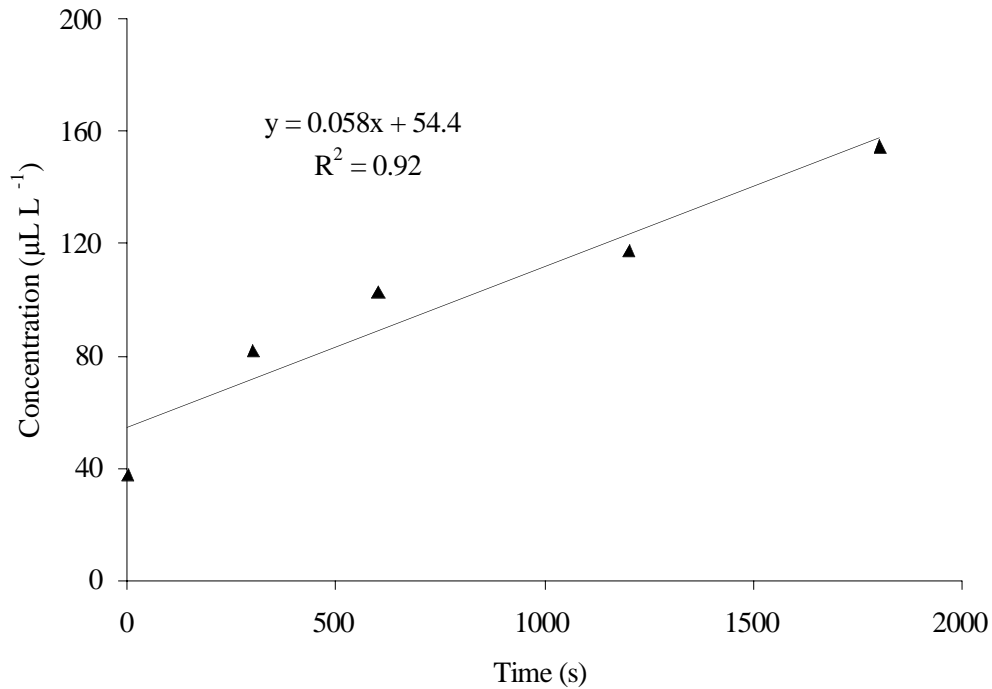


Figure 3. Estimation of emission rate ($\mu\text{L L}^{-1} \text{s}^{-1}$).

Greenhouse gas concentrations were converted into emission rates using an equation based on ideal gas law (Equation 1). The ideal gas law states that:

$$PV=nRT_k \dots\dots\dots 1$$

Where:

P= Pressure (1 atm at standard pressure)

V= Volume of gas (L)

N= Number of moles

R= Universal gas constant ($0.08207 \text{ L atm mol}^{-1} \text{ K}^{-1}$)

T_k= Temperature in Kelvin (absolute), (273.15 K at standard temperature)

Rearranging Equation 1 yields an expression for the molar volume (v_m) of an ideal gas at standard temperature and pressure:

$$v_m = \frac{V}{n} = \frac{R^*T_k}{P} \dots\dots\dots 2$$

Substitution of the values yields for standard temperature and pressure:

$$v_m = 22.4 \text{ L mol}^{-1} \text{ of GHG}$$

The concentration flux was converted into emission rate using the following equation:

$$\dot{m} = \left[\frac{\dot{C}}{10^6} \right] \frac{M V_s}{v_m A_s} \dots\dots\dots 3$$

Where,

\dot{m} = Mass flux per unit area ($\text{g s}^{-1}\text{m}^{-2}$)

\dot{C} = Rate of change in concentration ($\mu\text{L L}^{-1} \text{ s}^{-1}$)

M= Molar mass of GHG ($\text{CO}_2= 44$, $\text{CH}_4= 16$, and $\text{NO}_2= 46.01 \text{ g mol}^{-1}$)

V_s = Volume of static chamber, 3.33 L

A_s = Basal area of static chamber, (0.0184 m^2)

The mass flux rate (\dot{m}) was extrapolated over the entire pile by multiplying by the surface area of the pile. Off-gases were collected from the top of the pile and the emission rate from the entire pile was assumed to be uniform. There is always uncertainty involved in extrapolating emissions from the small area over the entire pile due to the high spatial variability of gas emissions through the surface of the pile. Previous studies indicated that the maximum emissions emit from the top surface of the piles (Wolter *et al.* 2004). This phenomenon can be explained due to the high temperature in the centre of the pile and a chimney effect by which air is drawn through the lower parts into the pile and warm air moves upwards in the centre resulting in convective aeration.

Greenhouse gas emissions obtained from the half-hour sampling time interval were assumed to be representative of daily emissions, and the daily emission rate was estimated by multiplying by a 24-h interval. There is always uncertainty involved when extrapolating data over extended periods because emissions rates vary with time depending on environmental conditions and other factors. Biogenic GHG emissions during the active composting phase from the compost pile and the manure stockpile were also expressed as kg CO₂ equivalent per unit time per unit initial dry mass.

Non-biogenic GHG analysis methodology

Machinery involved in material acquisition, transportation, turning of the compost pile, and spreading operations consumed fuel and contributed to GHG emissions. Greenhouse gas emissions estimations for CO₂, CH₄, and N₂O from fuel combustion were calculated by multiplying standard emission factors (Environment Canada 2002) with the amount of fossil fuel consumed by the machinery. Various equipment was used in this study, including a dump truck (S1700, International Truck and Engine corp., Warnerville, IL), a skid-steer loader (135-S, Thomas Equipment Ltd., Mississauga, ON); and a Komatsu front-end loader (WA120, Kamastu America Corp., Vernon Hills, IL) used to perform the following operations (Table 2).

Table 2 Machinery involved in each operation during this project

Operation	Machinery
Scraping and collection of manure	Front-end loader
Transportation of raw manure and establishment of piles	Dump truck and skid-steer loader
Turning of compost pile	Tractor-driven windrow turner
Transportation and application of end-product	Front-end loader and tractor with manure spreader

Raw feedlot manure was loaded onto a truck using a front-end loader and hauled with the dump truck to establish the compost pile and manure stockpile at the composting site. The compost pile was turned using a tractor-driven windrow turner (Earthsaver CT-12, Energy Harvesters Corp., Midland, TX) during the composting period. At the end of the study, the finished product was loaded onto a manure spreader (Series II-226, Hydra-Spread, Windsor, ON) with the front-end loader (135-S, Thomas Equipment Ltd., Mississauga, ON) and hauled to the application site. The amount of diesel fuel consumed by the machinery was estimated by recording the initial and final level in the fuel tank before and after each operation. The fuel tank of each machine was completely filled at the AAFC gas station near the composting site. The initial level of diesel fuel in the fuel tank was recorded. After each operation was performed, the machinery was driven back to the AAFC fill station. The fuel tank was topped up to the initial mark using a fuel pump and a 2-L graduated cylinder. The amounts of diesel fuel required to fill the fuel tank were measured using the graduated cylinder.

Greenhouse gas emissions were estimated by multiplying emission factors (g L^{-1} of diesel fuel consumed) by the amount of fuel used in each operation (Environment Canada 2002).

Statistical analysis

The data from biogenic GHG emissions from the compost pile and the manure stockpile were analyzed with the SAS Mixed Procedure. The data were tested for normal distribution. A mixed model with a repeated measures statement was used to test for significant effects. Statistical differences between the treatments (compost pile and manure stockpile) and time (days) and sampling zone were analyzed. Effects were deemed to be significant at $P < 0.05$. The treatment, day, and treatment*day interactions are fixed effects. The zone (within the treatments) and error (associated with the experimental design) are random effects.

RESULTS AND DISCUSSION

Biogenic GHG emissions

Carbon dioxide emissions

The mean hourly CO₂ fluxes from the compost pile and the manure stockpile ranged from 1.82-30.2 g m⁻² h⁻¹ and 2.7-25.3 g m⁻² h⁻¹, respectively (Figure 4). The lowest CO₂ emission rates were observed on the day that the piles were established. However, the highest CO₂ emissions were observed on Day 43 from the compost pile (30.2 g m⁻² h⁻¹) and on Day 2 from the manure stockpile (25.3 g m⁻² h⁻¹) (Figure 4).

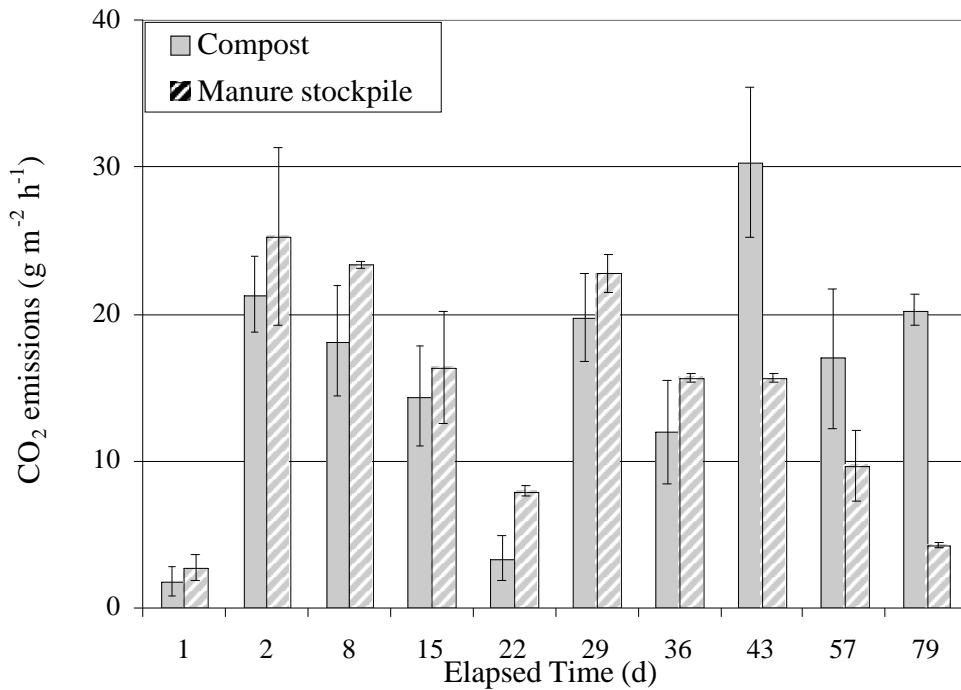


Figure 4. CO₂ emissions from compost and manure

Off-gases were collected immediately after the turning of the compost pile. Both piles emitted CO₂ emissions throughout the composting period. However, CO₂ emissions from the manure stockpile remained slightly higher until Day 36, but there was an opposite trend afterwards. The higher CO₂ emissions from the manure pile during the first month of the trial might have been due to the proper moisture content (M.C.) inside the pile. After one month of the trial, however, a thick crust has formed on the surface of the manure stockpile that might have lowered GHG emissions into the atmosphere. The immediate rapid increase in CO₂ emissions after Day 1 indicated that microbial decomposition was high during the initial stages in both the compost pile and the manure stockpile (Figure 4). During the mid stage of the composting process (after Day 36), comparatively higher CO₂ emissions were observed from the compost pile. This could have been due to the reshaping of compost pile. On Day 36, the length of the compost pile was reduced and the material was piled to increase the width and height of the pile. The reshaping of pile might have increased the microbial activity by redistributing and exposing substrate. The manure stockpile, on the other hand, was undisturbed and CO₂ emissions from the manure stockpile kept on decreasing after Day 29. This clearly indicates the strong effect of turning on

CO₂ emissions from the compost pile. Turning incorporates fresh air into the compost pile and increases the gas diffusion rate by increasing porosity of material; however, due to the static nature of manure stockpile, the layer of dry manure formed on the surface of the manure stockpile. This caused the development of unfavorable environmental conditions for aerobic microorganisms inside the unturned manure stockpile and hence, slower rate of decomposition and comparatively low CO₂ emissions.

Figure 5 presents the comparison of cumulative CO₂ emissions from the compost and manure piles. The total CO₂ emissions from the compost pile are high compared to those from the manure stockpile. This is in an agreement with the results of other studies (Hao *et al.* 2001). The treatments in that study (turned vs. unturned) had no significant ($P>0.05$) effect on CO₂ emissions.

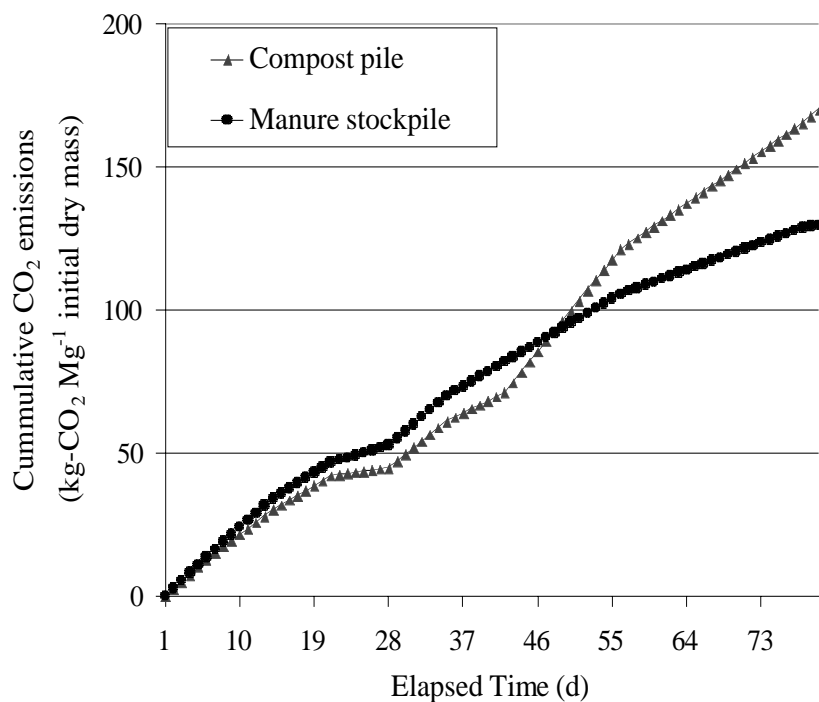


Figure 5. Cumulative CO₂ emissions from compost and manure

Methane emissions

The CH₄ emissions were lower from the compost than from the manure pile. Methane emissions from the compost were detected only during the initial and final stages of composting (Figure 6).

No CH₄ emissions were observed after Day 8 until Day 43 of the composting process from the compost.

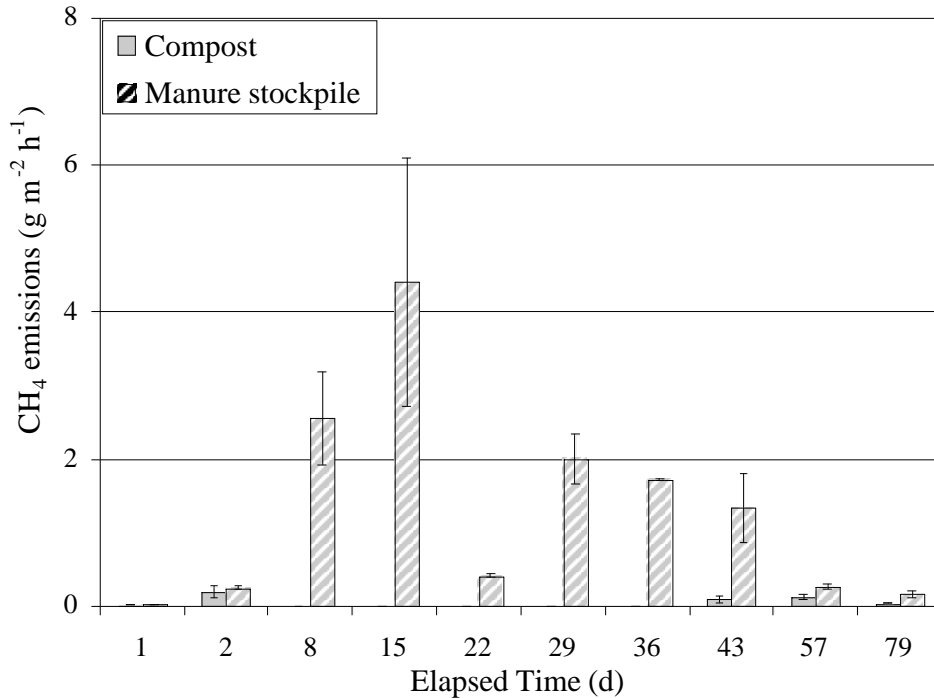


Figure 6. CH₄ emissions from compost and manure

The detection of CH₄ emissions from the compost during the initial stage of composting was quite similar to the patterns observed by Fukumoto *et al.* (2003) and Sommer and Møller (2000). No emissions were detected from Day 8 until Day 43. The lack of emissions from Day 8 until Day 43 indicates the effect of turning on the emission pattern. The compost pile was turned on a weekly basis during the first month after pile formation and once every two weeks after the first month of composting. The turning of the material favored development of aerobic conditions inside the compost pile. By turning the compost pile, the surface material was incorporated into the pile while material at the bottom was exposed at the surface. Therefore, the chances of CH₄ production due to the development of anaerobic zones inside the compost pile were minimal. Nevertheless, small methane emissions were observed after Day 36. A possible explanation could be the occurrence of anaerobic microsites inside the pile, resulting from compaction and reshaping of the compost pile. The compost pile was reshaped on Day 36 by reducing the length of the pile and increasing the height and width. Regular turning of the compost resulted in more

uniform and smaller-sized aggregates. The compactness and bulk density increased in the compost pile during the trial and some anaerobic microsites could have developed inside the pile. On Day 36, 6000 L of water were added to the compost pile and CH₄ emissions were observed the following week. The water addition might have created wet conditions inside the pile which are favorable for CH₄ generation. It is also suspected that at least some incomplete decomposition of organic material occurred at those sites due to the larger pile size and interrupted air flow through the compost pile causing the small methane emissions after reshaping. The results are consistent with the findings of Fukumoto *et al.* (2003), where a large compost pile (0.9 m height and 2 m diameter) showed high CH₄ emissions as compared to a smaller compost pile (0.7 m height and 1.4 m diameter), probably due to the existence of some anaerobic sites in the large pile. Fukumoto *et al.* (2003) in their study emphasized that the scale of the manure pile is an important factor in gas emission rates: as the size of the manure pile increased, the number and size of anaerobic sites also increased. He *et al.* (2000) also stated that even under aerobic conditions, anaerobic micro-sites may still exist inside aggregates.

Comparatively high CH₄ emissions were detected from the manure throughout this trial (Figure 6), indicating the presence of an anaerobic environment inside the manure stockpile. Methane emissions peaked at 4.4 g m⁻² h⁻¹ on Day 15. The lack of turning restricted air flow and moisture losses, creating an anaerobic environment conducive to CH₄ production. The CH₄ emission pattern from the manure stockpile agrees well with the findings of previous studies (Sommer and Møller 2000; Hellmann *et al.* 1997).

Figure 7 shows the comparison of cumulative CH₄ emissions from the compost and manure. The total CH₄ emissions from the manure stockpile were very much higher (P<0.05) than those from the compost. The interaction between time and CH₄ emissions from the compost and manure also was a significant (P<0.05) effect.

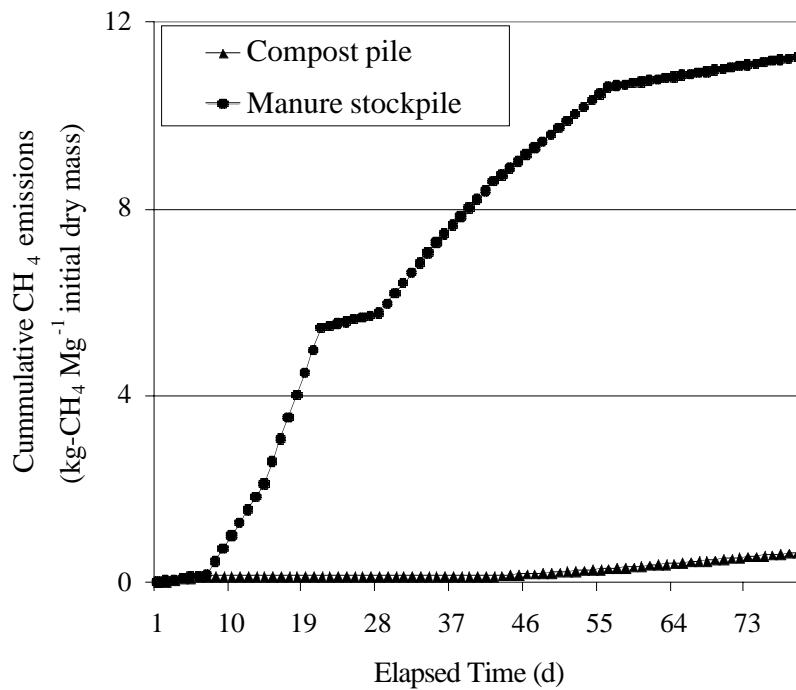


Figure 7. Cumulative CH₄ emissions from compost and manure

Nitrous oxide emissions

Compared with average CO₂ and CH₄ emissions from the compost pile (14.1 and 0.18 g m⁻² h⁻¹) and the manure stockpile (15 and 4.3 g m⁻² h⁻¹), average N₂O emissions from compost (12 mg m⁻² h⁻¹) and manure (17 mg m⁻² h⁻¹) were relatively low. However, N₂O emissions were less variable throughout the composting period (Figure 8). The small standard errors also indicate relatively small variation between N₂O emissions from the three different zones.

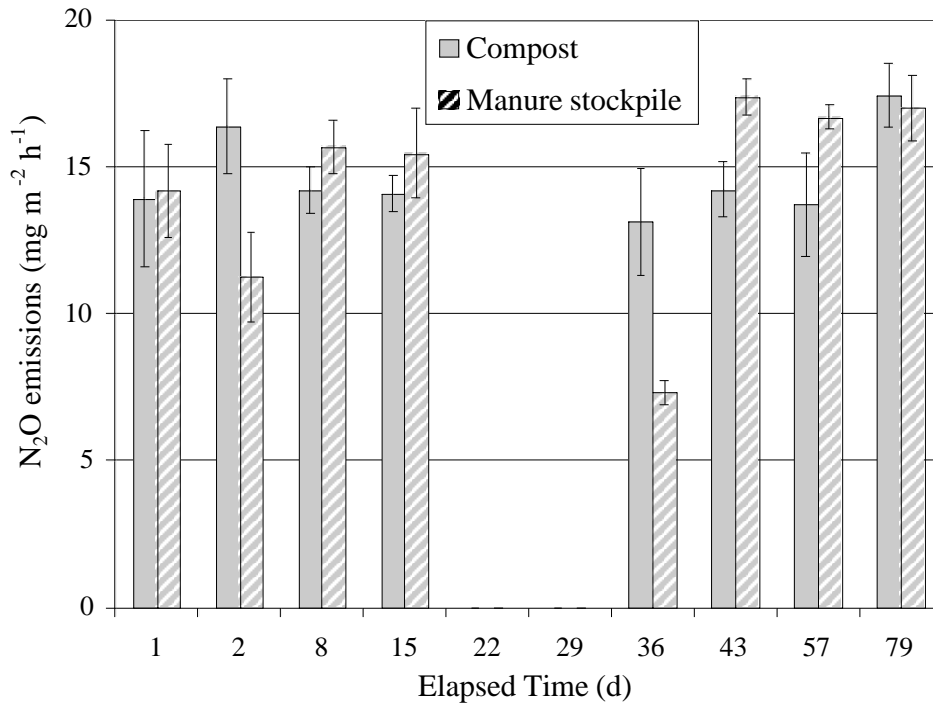


Figure 8. N₂O emissions from compost and manure

No significant ($P > 0.05$) differences were found in N₂O emissions from the compost pile and the manure stockpile. The maximum N₂O emissions were 17.4 mg m⁻² h⁻¹ on Day 79 and 17.5 mg m⁻² h⁻¹ on Day 43 from the compost pile and the manure stockpile, respectively. Only Day 21 and Day 29 did not show any N₂O emissions, otherwise the emissions were never observed to fall below 7.4 mg m⁻² h⁻¹. Some sampling error is suspected on these days.

In this study, the N₂O emissions rates observed during the trial were in agreement with the results of the study conducted by Hao *et al.* (2001) and Hellmann *et al.* (1997). Hao *et al.* (2001) found maximum N₂O emissions (15 g m⁻² h⁻¹) on Day 20 of the trial. After Day 20 of the trial, N₂O emissions remained below 3 g m⁻² h⁻¹. Several previous studies found that the N₂O emissions from livestock waste are influenced by the initial C:N ratio, moisture content, temperature, aeration, type of feedstock, compost age, pile depth, and the shape of the pile (Hellebrand 1998 and Hao *et al.* 2001). The initial C:N ratio in this experiment was very low (Table 1), the recommended range for effective composting being between 25 and 40:1 (Rynk 1992). Due to the low C:N ratio, the lack of organic carbon could have played an important role in N₂O leakage

from nitrification/denitrification reactions during the initial phase of decomposition, since N_2O is an intermediate product during of nitrification and denitrification. When organic carbon is not available in sufficient amounts in the material, the transformation of organic nitrogen into ammonia (NH_3) takes place. During the oxidation of NH_3 to nitrate, N_2O gas can be produced as a by-product during nitrification by autotrophic bacteria. He *et al.* (2001), in their study on GHG emissions from aerated composting, found an abrupt increase in N_2O emissions immediately after the depletion of available organic carbon.

During the later stages of composting (from Day 36 onwards), an increasing trend in N_2O emissions from both the compost and the manure was observed (Figure 8). This is similar to the pattern observed by He *et al.* (2001), in which peak N_2O emissions occurred at the end of the composting process. Denitrification might be a cause of N_2O gas production during the latter stages of composting when more anaerobic sites develop. Nitrous oxide gas is emitted as a byproduct during the denitrification of nitrate (NO_3^-) into nitrogen (N_2). The denitrification process is mainly influenced by oxygen concentration, temperature, and moisture content. The compost pile was reshaped on Day 36 and subsequently more water was added to the compost pile. It is therefore likely that the addition of water created anaerobic sites inside the pile. The turning of the compost pile also increased the compaction and bulk density of the material. The occurrence of anaerobic micro-sites and consequently N_2O emissions through denitrification were likely greater in the deeper and more compacted compost pile during latter stages of the trial (after Day 36). The formation of a thick surface layer of manure on the unturned manure stockpile might have created anaerobic conditions by restricting air flow into the pile.

Figure 9 compares cumulative N_2O emissions from the compost and the manure. Cumulative N_2O emissions from the compost were higher than from the manure. However, no significant difference ($P>0.05$) was found among N_2O emissions from the compost and the manure.

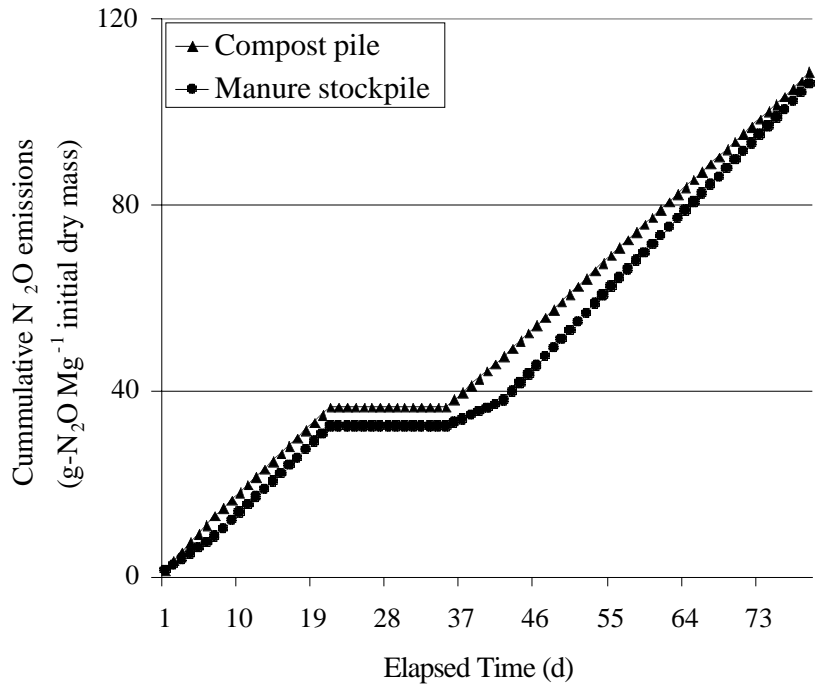


Figure 9 Cumulative N₂O emissions from compost and manure

Non-biogenic GHG emissions

Table 3 presents the amount of fuel consumed and the related non-biogenic GHG emissions. The total GHG emissions are estimated per ton (Mg) of initial dry mass.

Table 3 Non-biogenic sources and related GHG emissions per Mg initial dry mass.

	Fuel consumed	CO ₂	CH ₄	N ₂ O	Equivalent CO ₂
	L Mg ⁻¹	← g Mg ⁻¹ →			kg Mg ⁻¹
Compost Pile					
hauling and pile formation	1.69	4614	0.44	0.68	4.83
turning	0.55	1502	0.15	0.22	1.58
hauling and spreading	2.1	5733	0.55	0.84	6.04
Total					12.50
Manure Stockpile					
hauling and pile formation	1.53	4177	0.40	0.61	4.4
hauling and spreading	2.6	7098	0.68	1.1	7.4
Total					11.8

Net GHG emissions comparison

Figures 10 and 11 compare net biogenic and non-biogenic GHG emissions from the compost pile and manure stockpile. Biogenic GHG emissions from the manure were significantly ($P < 0.05$) higher than from the compost (Figure 10) mainly due to CH₄ release, which indicates that anaerobic conditions were present in the manure stockpile. The overall non-biogenic GHG emissions associated with compost were slightly higher than those from the manure (Figure 11). However, as compared to the biogenic GHG emissions, the non-biogenic GHG emissions were small. It is worth mentioning that regular turning of the material contributed about 13% of non-biogenic emissions associated with the compost whereas spreading and hauling of residual from the manure stockpile contributed 63% of non-biogenic emissions.

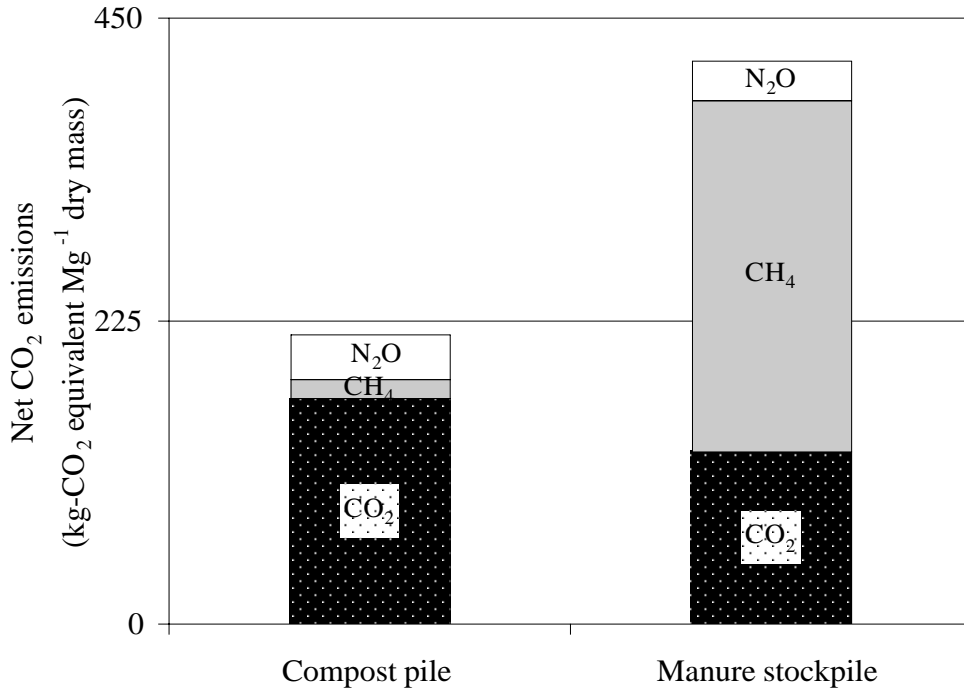


Figure 10. Biogenic GHG emissions

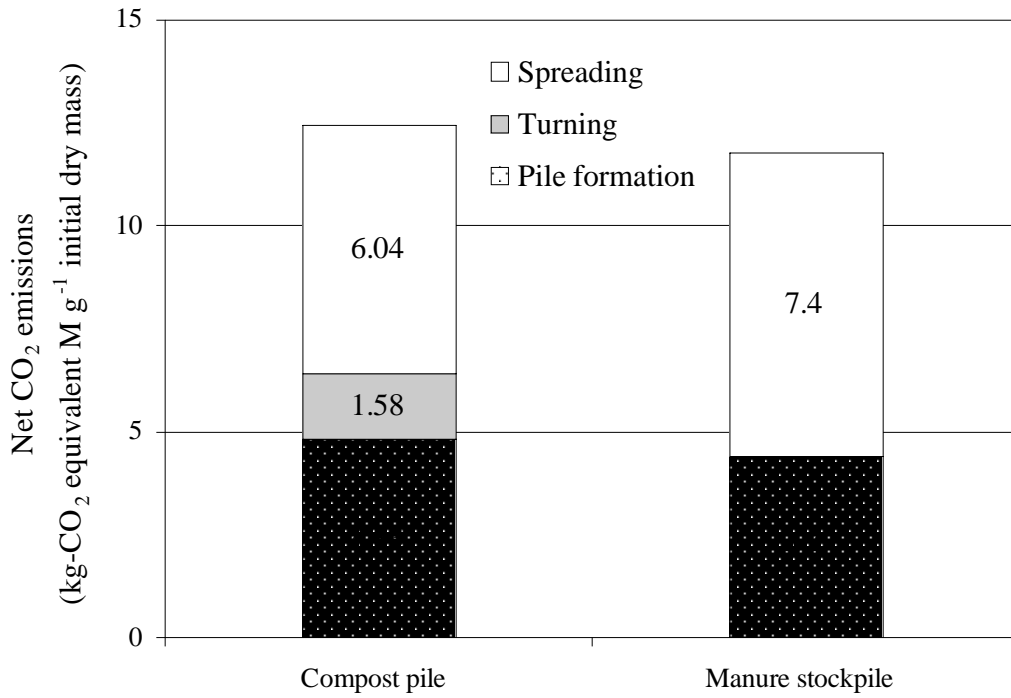


Figure 11. Non-biogenic GHG emissions

CONCLUSIONS

From this study it can be concluded that the total GHG emissions (biogenic and non-biogenic) from the manure stockpile were 48% higher compared to those from the compost pile. The higher GHG emissions from the manure stockpile were mainly due to CH₄ release. The CH₄ emissions in terms of CO₂ equivalent contributed 61% of biogenic GHG emissions from the manure stockpile. Biogenic GHG emissions (mainly CH₄ release) from the compost were lower (6% of biogenic GHG emissions) than from the manure (62%) due to the aerobic conditions maintained in the compost pile through frequent turning during the course of the trial. The higher non-biogenic emissions from the compost were primarily associated with fuel combustion during the turning of the compost pile. Turning contributed almost 13% of total non-biogenic GHG emissions. However, non-biogenic GHG emissions from both the piles were small compared with the biogenic GHG emissions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance and funding support provided by Alberta Agriculture, Food and Rural Development (AAFRD).

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